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EXPERIMENTAL VERIFICATION OF AN OPTIMAL LINEAR CONTROLLER FOR A FLEXIBLE STRUCTURE

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Nanometer accuracy in many space applications requires that sensors be isolated from vibration disturbances by the main spacecraft body. The Flexible Spacecraft Simulator (FSS) at the Naval Postgraduate School is designed for testing multiple control system designs. The experimental setup simulates a microgravity environment for a flexible Structure. A twenty-four state finite element model is used to characterize the flexible appendage. Piezoelectric ceramic wafers bonded to the structure are the actuators and sensors. A *VisionServer* external infrared camera provides direct feedback of the flexible structure's elbow and tip displacements to sub-millimeter accuracy. A Multiple-Input-Multiple-Output (MIMO) Linear Quadratic Gaussian (LQG) controller is experimentally compared with a Positive Position Feedback/Velocity feedback controller. The damping is increased on the order of 825% for both control implementations. The objective is to minimize the disturbance of the tip of the flexible structure, representing the reflector support point.

ORBITAL PERTURBATION ANALYSIS OF EARTH-CROSSING ASTEROIDS

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Earth-Crossing Asteroids (ECAs) are those asteroids whose orbit cross-section can intersect the capture cross section of the Earth as a result of secular gravitational perturbations. This thesis provides a framework for understanding the origin, nature, and types of ECAs. The change in velocity requirements to achieve a two Earth radii deflection for long- and short-term warning scenarios are developed. Next, a method of developing hypothetical Earth colliding asteroid orbits is presented. These hypothetical orbits are used in two ways: (1) to evaluate the ability of *Dance of The Planets*, a solar system simulation model developed by Applied Research and Consulting, Inc., to accurately propagate orbits of imported asteroid orbits, and (2) to analyze the sensitivity of deflection distance to variation in deflection angle and orbital parameters of a given orbit. Inaccuracies during importation of data precluded the use of *Dance of the Planets* for the purpose of sensitivity analysis. The program does provide an excellent tool for visualization of ECA scenarios. Consequently, a simpler orbital model was developed to provide a Earth miss distance sensitivity analysis. With one asteroid orbital period warning the minimum change in velocity to deflect an asteroid two Earth radii is approximately 0.135 m/s and the optimal deflection is along the flight path. Maximum deflection occurs when the deflection is applied at perihelion. The miss distance decreases markedly with increase in true anomaly until it is a minimum at aphelion.

AN ANALYSIS OF SPACECRAFT DYNAMIC TESTING AT THE VEHICLE LEVEL

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The U.S. space industry has accumulated a vast amount of expertise in the testing of spacecraft to ensure these vehicles can endure the harsh environments associated with launch and on-orbit operations. Even with this corporate experience, there remains a wide variation in the techniques utilized to test spacecraft during the development and manufacturing process, particularly with regard to spacecraft level dynamics testing. This study investigates the effectiveness

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of sinusoidal vibration, random vibration, acoustic noise and transient methods of spacecraft dynamic testing. An analysis of test failure and on-orbit performance data for acceptance testing indicates that the acoustic test is the most perceptive workmanship screen at the vehicle level and that additional dynamics tests do not result in an increase in acceptance test effectiveness. For spacecraft qualification, acoustic testing is almost universally employed for qualification in the high frequency environment. For the low frequency environment, data collected from a variety of spacecraft test programs employing sinusoidal sweep, random vibration and transient testing methods shows that a transient base excitation provides the most accurate simulation for the purpose of design verification. Furthermore, data shows that sinusoidal vibration testing provides an unrealistic simulation of the flight environment and results in an increased potential for over testing.

EVALUATION OF THE STRAIN ENERGY DENSITY METHOD OF NOTCH STRESS CONCENTRATION CALCULATIONS IN THE PLASTIC RANGE

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Accurate stress and strain calculations at a notch usually require a nonlinear finite element analysis when local yielding has occurred. The strain energy density hypothesis is a method to predict these stress and strain values. This method proposes that the plastic strain energy density is equivalent to the strain energy density found assuming the material to be entirely elastic. This hypothesis was evaluated using the finite element method, which was tested by comparing two exact solutions of elastic and elasto-plastic problems, to calculate the stress and strain field for two notched plates of varying widths under elasto-plastic loading. For both geometrics, a plane stress and plane strain analysis was performed.

The elasto-plastic strain energy density from the finite element method was found to be greater than that predicted by this proposal, which in turn resulted in under-predicting the local stresses and strains. This difference was greater for the plane stress condition than for the plane strain condition. Comparisons were also made with notch stresses based on the Neuber method. The two methods appear to give an upper and lower bound to the actual stresses and strains. By combining the results of the strain energy density method and the Neuber method, reasonably accurate estimates of stress and strain values can be obtained.

PERFORMANCE AND OPTIMAL PLACEMENT OF PIEZOCERAMIC ACTUATORS FOR SHAPE CONTROL OF A CANTILEVER BEAM

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Shape control of spaceborne antennas can provide the ability to correct for effects such as thermal distortion and manufacturing errors as well as control the shape of an antenna's radiated beam. This thesis examines the performance of piezoceramic actuators in producing static deformation of a cantilever beam and analyzes the optimal placement of actuators to best approximate a desired deformation profile. Predictions of actuator effectiveness at producing curvature are developed using an Euler-Bernoulli model. An algorithm to determine the optimal locations and input voltages for a fixed set of actuators to achieve a desired deformation profile of a cantilever beam using embedded Nelder and Mead simplex search routines is presented and evaluated for two shape functions and various combinations of actuators. Experimental measurements show that the Euler-Bernoulli model provides a reasonable prediction of actuator performance at low input voltage but does not account for nonlinear behavior of the piezoceramic and the effects of hysteresis and transverse stresses. Further experiments demonstrate the ability of four piezoceramic actuators to pro-

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duce an approximation of a parabolic deformation profile of a cantilever beam and illustrate the importance of considering these effects in determining the required actuator input voltages.

INTEGRAL HYBRID-BOOST/SOLID-FUEL RAMJET PROPULSION FOR LIGHTWEIGHT TACTICAL MISSILES

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An investigation was conducted to determine the feasibility of a small, low-cost, caseless, hybrid-booster/solid-fuel ramjet (H/SFRJ) that utilizes a common fuel grain and has no ejectables. Performance of an air-to-ground missile with a solid propellant booster and SFRJ sustainer, capable of being fired from an unmanned aerial vehicle or helicopter was obtained using an Air Force computer code. A H/SFRJ motor was then designed analytically and compared to the generated computer output. The results showed that a H/SFRJ that has performance equal to a solid-booster SFRJ is feasible. The final missile design had a range of 20 nm, a flight Mach number of 2.0, a diameter and length of 5 and 99 inches respectively, and weighed 82 lb. Caseless hybrid rockets with erodible nozzles were tested to validate assumptions made in the design analysis. In addition, transition from hybrid-rocket booster to solid-fuel ramjet sustainer was demonstrated.

